

Radiation

Determining the Magnitude of Neutron and Galactic Cosmic Ray (GCR) Fluxes at the Moon using the Lunar Exploration Neutron Detector (LEND) during the Historic Space-Age Era of High GCR Flux

The Lunar Reconnaissance Orbiter (LRO) was launched June 18, 2009 during an historic space age era of minimum solar activity. The lack of solar sunspot activity signaled a complex set of heliospheric phenomena that also gave rise to a period of unprecedentedly high Galactic Cosmic Ray (GCR) flux. These events coincided with the primary mission of the Lunar Exploration Neutron Detector (LEND), onboard LRO in a nominal 50-km circular orbit of the Moon. LEND measures the leakage flux of thermal, epi-thermal, and fast neutrons that escape from the lunar surface. Neutrons are produced within the top 1-2 meters of the regolith by spallation from the GCR flux. The energy spectrum and flux of the emergent neutron population is highly dependent on the incident flux of the GCR due to its influence on the depth of neutron production and total number of neutron-producing events. Methods to calculate the emergent neutron albedo population using Monte Carlo techniques rely on an estimate of the GCR flux and spectra calibrated at differing periods of solar activity. Estimating the actual GCR flux at the Moon during the LEND's initial period of operation requires a correction using a model-dependent heliospheric transport modulation parameter to adjust the GCR flux appropriate to this unique solar cycle. These corrections have inherent uncertainties depending on model details. Precisely determining the absolute neutron and GCR fluxes is especially important in understanding the emergent lunar neutrons measured by LEND and subsequently in estimating the hydrogen/water content in the lunar regolith. Simultaneous measurements of the LEND detectors determine the absolute GCR and neutron flux levels: LEND is constructed with a set of neutron detectors to meet differing purposes. Specifically there are two sets of detector systems that measure the flux of epithermal neutrons: a) the uncollimated Sensor for Epi-Thermal Neutrons (SETN) and b) the Collimated Sensor for Epi-Thermal Neutrons (CSETN). LEND SETN and CSETN observations form a complementary set of simultaneous measurements that determine the absolute scale of emergent lunar neutron flux in an unambiguous fashion and without the need for correcting to differing solar-cycle conditions. LEND measurements are combined with a detailed understanding of the sources of instrumental background, and the performance of CSETN and SETN. This straightforward estimation has been verified with detailed simulations of the LRO spacecraft and its influence on SETN and CSETN using the Geant4 Monte-Carlo framework developed at CERN. This comparison allows us to calculate a constant scale factor that determines the absolute flux of neutrons at the Moon and then subsequently to deduce the proper scale of the GCR flux model without correction or use of the heliospheric modulation potential for this unique solar cycle minimum.

Radiation

Space Weathering Investigations Enabled by Virtual Energetic Particle Observatory and the Space Physics Data Facility

The NASA Virtual Energetic Particle Observatory (VEPO) and Space Physics Data Facility (SPDF) collaborate on provision of data products and services of strong potential use for modeling of space weather and resultant surface weathering on inner and outer solar system objects, and for radiation hazard assessments related to robotic and future human exploration missions. The VEPO services are provided in direct collaboration with the DREAM2 team of SSERVI. Current VEPO services include intercomparison of differential flux spectra for protons, helium, and heavier ions from operational missions including the Advanced Composition Explorer (ACE), WIND, SOHO, and STEREO-A/B. Older mission data are also available for comparison from earlier epochs for Ulysses, IMP-8, Helios-1/2, Pioneer-10/11, and Voyager-1/2. As discussed, the differential flux spectra can be transformed with radiation transport models, e.g. GEANT, into depth dosage and surface sputtering profiles useful for modeling of space weathering effects and radiation hazards. Long term averages can be computed to simulate solar cycle effects. A further important application is to compare flux data from different sensors and spacecraft to check instrument calibrations.

Radiation

Laser Space Weathering of Carbon: What can we expect from NEO sample return?

Two upcoming missions, OSIRIS-REx and Hayabusa-2, plan to visit B- and C-type asteroids in order to return pristine samples of these asteroids. If these asteroids are indeed carbonaceous, then they may contain up to ~5% organic carbon, mainly in the form of macromolecular carbon (MMC). MMC in meteorites can be studied with Raman spectroscopy. Changes in its Raman spectral parameters correlate with the petrographic grade of the meteorite. But these petrographic studies are calibrated with internal pieces of meteorite samples, so the MMC seen in meteorites may not have experienced space weathering. Carbonaceous meteorites that contain space-exposed asteroid regoliths are uncommon in meteorite collections and it is uncertain if asteroid regolith samples we have are representative of asteroid regolith. Hence, it is important to determine the effects space weathering may have on the MMC and on its Raman spectrum. Laser pulse heating experiments that simulate the micrometeorite impact component of space weathering have been carried out in 30 s increments on uncompressed powders of pure graphite and a sample of Allende, which is a CV petrologic type 3 carbonaceous chondrite. Powders were contained within a glass sample cup. Pulse heating was done in vacuum (1×10^{-6} torr) with a 1064 nm Nd:YAG laser running at 20 Hz, a 6 ns pulse duration (30 mJ/pulse), and a 200 μ m spot size. Raman spectra were collected on the each sample using a WITec alpha300 R confocal Raman microscope, with a 45.5 μ W 532 nm continuous laser and a $\sim 10 \mu$ m laser spot size. Preliminary results show that Raman spectra of the original graphite powder exhibit dramatic changes. The original pure graphite is modified to disordered graphite by 10 minutes (60,000 laser pulses), and further modified to glassy carbon (nanocrystalline 3-coordinate carbon) within 20 minutes (120,000 laser pulses). Vapor deposited on the side of the sample holder has a Raman spectrum consistent with amorphous carbon glass (3- and 4-coordinate carbon). Changes to the Raman spectrum for Allende are much more subtle than the graphite experiments and no amorphous carbon is detected as a vapor deposit. There is a much lower concentration of carbon in Allende compared to pure graphite, so the weathered MMC Raman signals might be below the detection limit. The majority of Allende is silicate minerals. It is possible that melt and vapor deposited silica rims may contain a few percent carbon, but TEM measurements are needed to confirm this hypothesis. TEM studies of the space-weathered graphite are needed to confirm the phase change from graphite to glassy carbon, to confirm the presence of amorphous carbon, and determine the carbon coordination number of these phases. TEM studies of Allende might show small amount of weathering of the MMC, which may exhibit a different carbon coordination number compared to the space-weathered graphite. Additional meteorite classes will be studied, such as type 2 CM (e.g. Murchison) and type 3.0 ordinary chondrites (e.g. Bishanpur).

Radiation

Understanding Tissue Equivalents Radiation Interactions in a Worsening Radiation Environment

The Sun and its solar wind are currently exhibiting extremely low densities and magnetic field strengths, representing states that have never been observed during the space age. As a result of the remarkably weak solar activity, we have also observed the highest fluxes of galactic cosmic rays in the space age, and relatively small solar energetic particle events. We examine the implications of these highly unusual solar conditions for human space exploration. The worsening radiation conditions in space motivate further validation of our understanding of the radiation interactions, particularly due to secondary populations behind shielding, at high altitude and in deep space. A new detector concept, Dose Spectra from Energetic Particles and Neutrons (DoSEN), combines two advanced complementary radiation detection concepts with fundamental advantages over traditional dosimetry. DoSEN not only measures the energy but also the charge distribution (including neutrons) of energetic particles that affect human (and robotic) health in a way not presently possible with current dosimeters. For heavy ions and protons, DoSEN provides a direct measurement of the Lineal Energy Transfer (LET) spectra behind shielding material. For LET measurements, DoSEN contains stacks of thin-thick Si detectors similar in design to those used for the Cosmic Ray Telescope for the Effects of Radiation (CRaTER). CRaTER is the first instrument of its kind to provide the needed ground truth measurements of LET spectra that provide the direct and critically-needed link between biological effectiveness to the radiation environment. With LET spectra, we can now directly break down the observed spectrum of radiation into its constituent heavy ion components and through biologically-based quality factors provide not only doses and dose-rates, but also dose-equivalents, associated rates and even organ doses. DoSEN also measures neutrons from 10-100 MeV, which requires enough sensitive mass to fully absorb recoil particles that the neutrons produce. The penetrating nature of the neutrons is offset by their intensity and sufficiently long exposure times, thus the constraining envelope dimension is the range of the recoil particles—typically protons in hydrogenous material. Because it is prohibitive to make a detector large enough to absorb the full energy of each neutron, the response of the instrument is broad, but still the task of measuring the spectrum and intensity in the featureless neutron spectrum is straightforward. Such technology has been in use for decades, but adapting it to the smallest, most efficient and lowest mass envelope is challenging. DoSEN develops the new concept of combining these independent measurements, and using the coincidence of LET measurements and neutron detection to significantly reduce backgrounds in each measurement. The background suppression through use of coincidence allows for significant reductions in size, mass, and power needed to provide measurements of dose, neutron dose, dose-equivalents, LET spectra, and organ doses. As we enter a new regime for the space environment due to drastic changes in solar behavior, the DoSEN concept lays a fundamental new groundwork for improving our understanding of the unique primary and secondary populations that cause biological damage.